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(CLIC, Drive Beam Decelerator, Wake fields)

STATUS REPORT OF THE CTF3 TEST BEAM LINE

S. Döbert, D. Schulte, I. Syratchev

Abstract

The Test Beam Line (TBL) in CTF3 is a dedicated experiment to validate the drive beam decelerator concept of CLIC. The stability of the drive beam deceleration and the efficiency of rf power production is one of the key issues on the way to demonstrate the feasibility of the CLIC concepts. The TBL will be installed in the new CLIC Experimental Area (CLEX) currently under construction. This report describes the design of the TBL in its main components as well as the status of the project planning including a preliminary schedule and cost estimate.

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STATUS REPORT OF THE CTF3 TEST BEAM LINE

Steffen Döbert, Daniel Schulte, Igor Syratchev

INTRODUCTION

In CLIC, the rf power to accelerate the main beam is produced by decelerating a drive beam. The Test Beam Line (TBL) of the CLIC Test Facility (CTF3) is designed to study and validate the drive beam stability during deceleration. This is one of the R&D items required from the International Linear Collider Technical Review Committee to demonstrate feasibility of CLIC. It will produce high frequency rf power in the GW range and allow to benchmark computer codes used for the CLIC decelerator design.

The CLIC test facility will demonstrate the essential parts of the CLIC drive beam generation scheme consisting of a fully loaded linac, a delay loop and a combiner ring [1]. The final CTF3 drive beam delivered to the CLIC Experimental Area (CLEX) comprising the test beam line and a two beam test stand, has an energy of 150 MeV, 35 A of beam current, a bunch repetition frequency of 15 GHz and a pulse length of 140 ns. The emittance is assumed to be 150 μm and the bunch length 0.6 mm rms. Main differences between the CTF3 beam and the CLIC drive beam are the energy and the current. The CLIC drive beam has a beam current of 180 A and is decelerated from 2.3 GeV to 0.23 GeV giving up 90% of its energy.

The main aims of the TBL sub-project of CTF3 are:

- to study and demonstrate the technical feasibility and the operability of a drive beam decelerator (including beam losses) with extraction of as much beam energy as possible.
- to demonstrate the stability of the decelerated beam and the produced rf power.
- to benchmark the simulation tools in order to validate the corresponding systems in the CLIC nominal scheme.

The main issues are the transport of a beam with a very high energy spread with no significant beam loss and suppression of the wake fields from the power extraction and transfer structures (PETS). Additional goals for TBL are the test of alignment procedures and the study of the mechanical layout of a CLIC drive beam module with some involvement of industry to build the PETS and rf components. Finally TBL will produce rf power in the GW range which could be used to test several accelerating structures in parallel.

POWER EXTRACTION STRUCTURE

The most demanding and restricting component in TBL is the PETS. The main emphasis in designing PETS for TBL was on extracting as much power as possible while balancing the wake field effects and providing enough geometrical aperture for the beam to pass. Furthermore the PETS tested in TBL should be as close as possible to the actual CLIC design. Recently, the base line design of the CLIC PETS [2] was evaluated in order to reduce the peak power to be produced by the single structure by a factor two. The new 16 mm aperture ($a/\lambda=0.8$) PETS consists of eight identical racks with shallow corrugations separated by 1.5 mm slots for the damping of the transverse HOM, and equipped with a new very compact and efficient rf power extractor based on a single mode approach, see Figure 1.

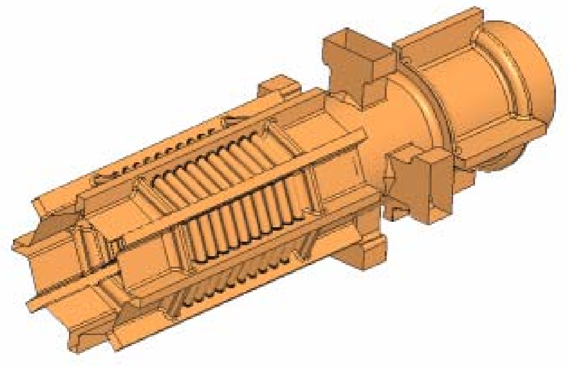

Figure 1: The general view of the 16 mm aperture PETS with 4-channel RF power extractor. The number of cells is not to scale.

In this design the 72 degrees phase advance per cell was chosen to reduce the impedances of very high order modes whilst keeping very strong damping for the dangerous modes and additionally to place the transverse wake zero crossings closer to the position of the bunches. The transverse wake impedances and amplitudes simulated with GDFIDL [3] are shown in Figures 2 and 3. The new PETS parameters are summarized in Tables 1 and 2.

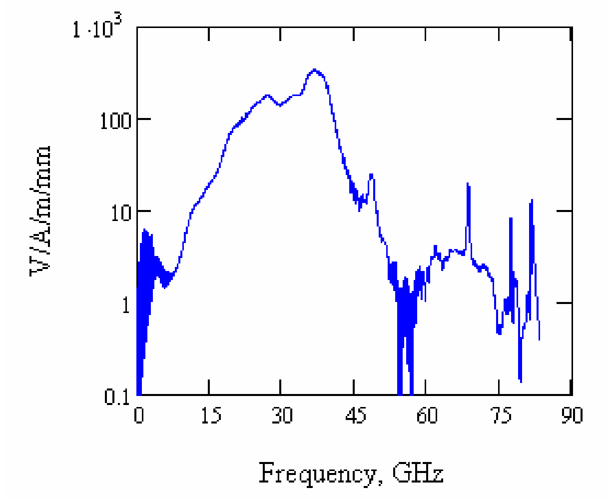

Figure 2: The transverse wake impedances for the new PETS design.

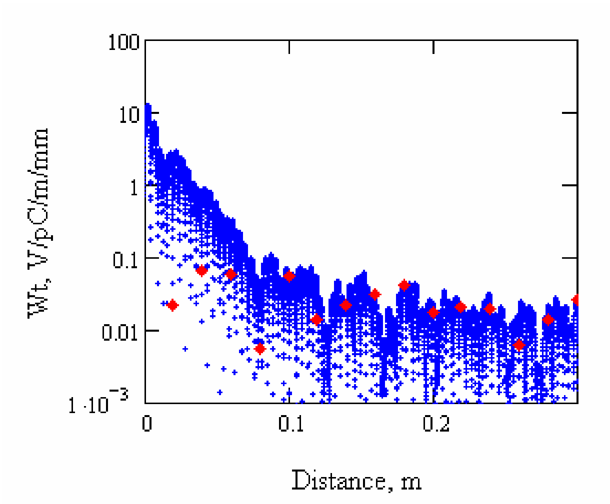

Figure 3: The new PETS transverse wake envelope. The diamonds corresponds to the wake amplitudes at the centre of the bunches.

Table1: The CLIC PETS decelerating mode.

Frequency, GHz	29.9855
R/Q, Ω	1150
V group/ *C*	0.74
Q factor	6500

Table 2: The CLIC PETS transverse modes.

Mode number	Frequency, GHz	Wt V/pC/m/mm	Loaded Q factor
1	20	0.56	5.4
2	24.6	4.14	2.8
3	27.2	2.96	5.2
4	32.3	2.55	7
5	36.45	5.32	9.9
6	38.6	3.64	11

It turns out that the new PETS configuration is well suited to the TBL needs. The design of TBL PETS is identical to the CLIC PETS except for the length, which is about twice as long to be able to extract enough power despite the lower beam current of CTF3. The PETS for TBL have therefore an active length of 0.8 m

The aperture appears to be optimized for TBL as well because a bigger aperture would reduce the wake fields but would lower the impedance and therefore the amount of deceleration obtainable for the given length of the beam line. Lengthening the PETS would help in this respect but would compromise the lattice stability as discussed in the next chapter.

TBL DESIGN

The test beam line will consist of a series of FODO lattice cells and a diagnostic section at the beginning and end of the line to determine all relevant beam parameters. Each cell is comprised of a quadrupole, a BPM and a power extraction structure. Each quadrupole will be equipped with remotely controlled movers for beam based alignment. The quadrupoles and movers are developed by CIEMAT, Spain as a contribution to CTF3. The BPM's will most likely be a scaled version of the magnetic pick ups used in CTF3 and should reach a resolution of 5 μm [4]. The FODO lattice was chosen because of its energy acceptance. Due to transient effects during the filling time of the PETS the first 10 ns of the bunch train will have a huge energy spread from the initial energy down to the final energy of the decelerated beam. The lattice is optimized for the decelerated part of the beam, higher energy particles will see less focusing. The betatron phase advance per cell is close to the theoretical value of 90 degrees per cell for a round beam. A schematic of a TBL cell is shown in figure 4.

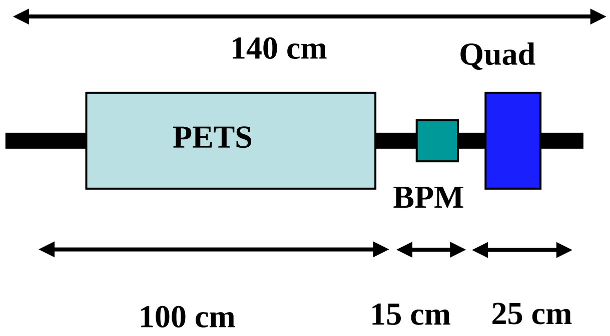

Figure 4: Schematic of a TBL cell.

The available space in CLEX allows the construction of up to 16 cells with a length of 1.4 m per cell. The nominal 35 A beam from CTF3 is decelerated by 5 MeV in each PETS, producing 160 MW of 30 GHz power. Already simple analytical calculation of the beam envelope assuming an ideal FODO lattice and taking into account the energy loss reveal that with the present CTF3 beam parameters the minimal transportable energy within the available aperture is 55 MeV. Figure 5 shows the beam energy and beam size as a function of the number of deceleration cells for the nominal beam parameters described above.

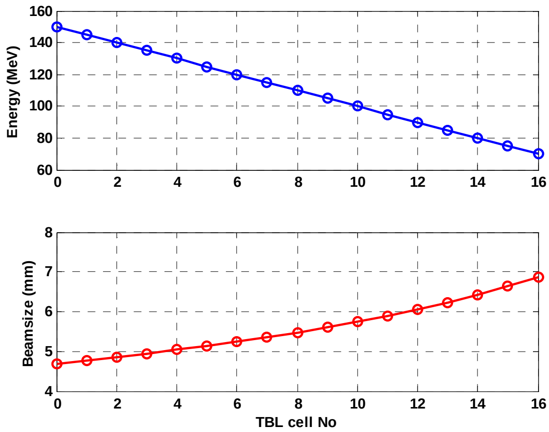

Figure 5: Energy profile and 3σ beam radius along the cells of TBL for the nominal beam parameters.

In this case 53 % of the available beam power would be extracted corresponding to 2.5 GW of 30 GHz rf power. The beam already fills most of the aperture although wake field effects and misalignment are not even taken into account. The properties of the higher order modes described in the previous chapter are used in a more sophisticated simulation with PLACET [5] to evaluate the effect of the wake fields. In TBL, the offset amplification factor due to wake fields is actually higher than expected in CLIC mainly due to the lower energy. The 3σ beam size along the line including the influence of various higher order modes is shown in figure 6.

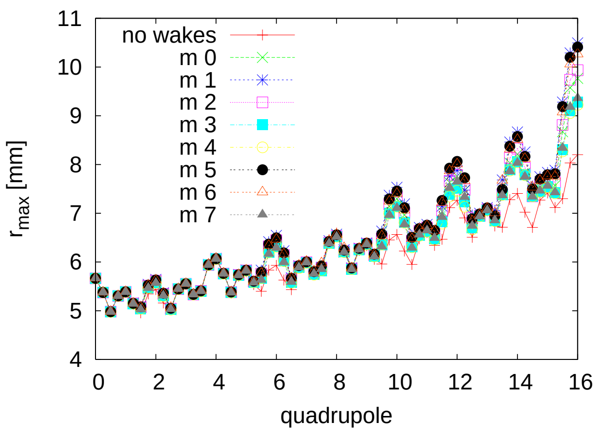

Figure 6: Maximum beam radius (3σ) along TBL. Simulations are done for a number of higher order modes and entirely without wake fields.

The wake field effects are responsible for about 20% of the beam size at the end of TBL. Therefore the minimum transportable energy in this line rises to 80 MeV which limits the extractable beam energy to 46% in TBL. For the nominal CTF3 beam parameters one would expect already some beam loss starting from cell 12 if the aperture in the quadrupoles is the same as in the PETS. Whether tapering out to a bigger aperture in the quads and BPM's is feasible has to be studied. The BPM aperture is specified to 22 mm to get the required resolution and the design of the quadrupoles would allow for 25 mm aperture assuming ±5 mm clearance to move the quadrupoles around the beam pipe.

The beta-function in a FODO lattice is proportional to the cell length. Shortening the cells would reduce the beam size accordingly but would reduce the active length for power extraction and therefore the extractable energy from the beam. A triplet lattice was excluded because of its lower energy acceptance. Significant improvement could come from a higher initial beam energy and a smaller emittance.

LAYOUT IN CLEX

The tentative layout of TBL in CLEX is shown in figure 7. The test beam line starts after the fist bending magnet of the chicane towards the two beam test stand. The diagnostic section in front of the bending magnet will be used for TBL experiments to determine the beam properties at the entrance of TBL but is formally (schedule and budget) a part of TL2. Therefore TBL starts with a matching section consisting out of a quadrupole doublet, a BPM and a pair of correctors to allow for parallel displacement of the beam to excite wake fields in a controlled way. The matching section is followed by 16 identical cells as described above consisting out of a quadrupole, a BPM and a PETS structure. At the end of the beam line a diagnostic section is installed allowing a characterisation of all relevant beam parameters. The section consists of a quadrupole doublet and an OTR screen dedicated to transverse beam profile and emittance measurements. A spectrometer with an angle of 10 degrees and a second screen will provide a measurement of the energy and energy spread. It is planned to install a segmented beam dump enabling time resolved energy measurements. The section is completed by a BPM and a BPR. The BPR will provide a signal proportional to bunch length. The total length of the line is about 32 m. Vacuum valves are foreseen after the bending magnet and before the Diagnostic section at the end of the line. The 16 cells will be a single vacuum sector.

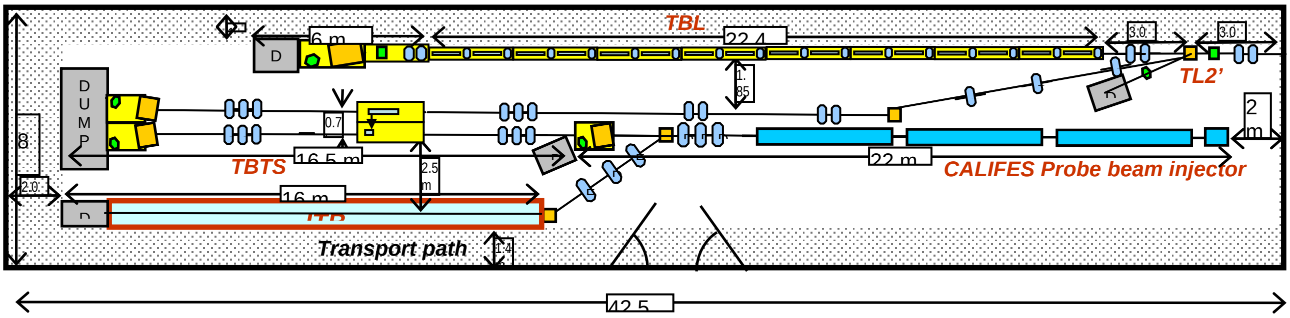

Figure 7: Tentative layout of the CLEX building with TBL.

CHOICE OF FREQUENCY

The design of the PETS for TBL aims for a maximum of power extraction with acceptable wake field effects. It is possible to leave the length and the deceleration constant while changing the frequency. Therefore one can replace the PETS described above with PETS having a different frequency in the modules. Lowering the frequency would even allow to increase the aperture somewhat. A preliminary study by Igor Syratchev for a PETS at 15 GHz showed that one can produce the same amount of rf power using the same length for the structure and an aperture around 22 mm.

Therefore it is assumed that in the range between 15 GHz and 30 GHz one can design a PETS structure which fits into the module, producing the same power. For lower frequencies the aperture can be increased somewhat which would help the beam transmission if the wake fields are at the same level as for 30 GHz which has to be studied in detail.

TENTATIVE SCHEDULE

A rough and schematic schedule to build the test beam line is shown in figure 8. In order to demonstrate the feasibility of the CLIC drive beam scheme by 2010, the design of TBL and most of the components should to be finished until the end of 2006. Most of the year 2007 is used to produce the parts needed for the complete beam line with its vacuum system, quadruples, diagnostics and if possible two PETS. Testing of prototypes will be necessary for the BPM's, the quadrupole with mover, the PETS and high power rf components in 2007 to validate the design before launching the series production. In this respect the schedule might be over optimistic. The installation of the beam line and two PETS is planned for the first half of 2008. First beam into TBL is hoped for in July 2008. The second half of 2008 would be used for commissioning of the beam line and first experiments with only two PETS installed. In the course of 2009 depending on availability and shutdowns successively more modules will be equipped with PETS. A milestone should be running TBL with 8 PETS installed before the end of 2009. TBL should be completed and running with 16 modules in 2010 demonstrating stable and reliable deceleration and rf power production.

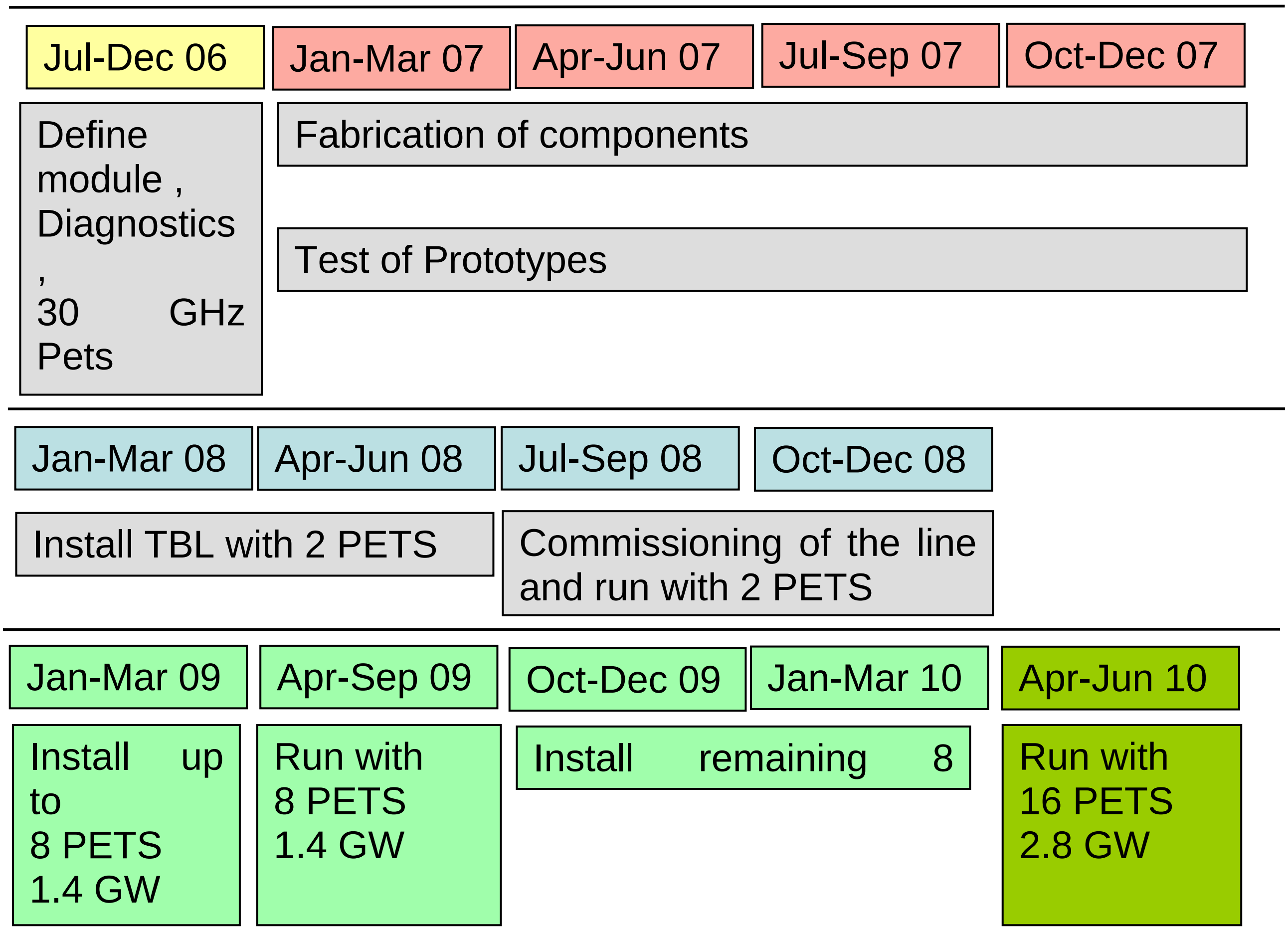

Figure 8: Tentative schedule of TBL

BUDGET

The following table shows a first crude estimate of the cost to build TBL. It shows the cost per component, the number of components needed and the spending profile needed according to the schedule. The spending profile needed is compared to the one foreseen in the current CTF3 budget planning. It is assumed that quadrupoles for matching and the spectrometer line are available at CERN. Quadrupoles and movers will be provided by CIEMAT. The BPM's for the modules might be provided by collaborations which are not confirmed yet, therefore their cost is included. There is a breakdown of the cost for the PETS which should be verified since it is the most expensive item for TBL. The diagnostic section in front of TBL is also estimated but not included in the total budget. All numbers are in units of kCHF.

TBL cost table							
Beam line building bloc	Device	Cost	No of devices	2007	2008	2009	Total
TBL-Line	PETS	160	16		320	2240	2560
	BPM	20	16		320		320
	BPM elctronics	5	16		80		80
	Quads+Movers	0	16				0
	Mover controls	2	16	32			32
	Quad PS	8	16		128		128

	Support structure	5	16	80			80
	Vacuum Pump/PS	10	16	80	80		160
	Cableing	10	16		160		160
	Miscellaneous	50	1		50		50
Matching section	Quads	0	2				0
	Quad PS	10	2	20			20
	BPM	31	1	31			31
	Corrector/PS	10	2	20			20
	Support	10	1	10			10
	Cableing	10	1		10		10
	Vacuum	10	1	10			10
Spectro line	Quads	0	2				0
	Quad PS	10	2		20		20
	BPM	31	1		31		31
	MTV	30	2		60		60
	Support	10	1		10		10
	Cableing	10	1		10		10
	Vacuum	10	1		10		10
	Dipole PS	10	1	10			10
	Corrector/PS	10	1	10			10
Yearly Sum				303	1289	2240	3832
Planned Budget				320	1280	700	2300
PETS	Tank	10	1				10
	Structure	100	1				100
	Load+Coupler	10	2				20
	Waveguides	10	1				10
	RF detector	10	2				20
	SUM						160
TL2' Diagnostic	Quads	0	2				0
	Quad PS+Dipole	10	3	30			30
	BPM	31	1	31			31
	BPR	30	1	30			30
	MTV	30	2	60			60
	Support	10	1	10			10
	Cableing	10	1	10			10

	Corrector/PS	10	1	10			10
	Vacuum	10	1	10			10
	SUM			191			191

OTHER RESOURCES

The commitment from certain groups at CERN (Controls, BI, Vacuum, TS) has to be negotiated for this project.
In addition special Man or Woman power is needed for the following tasks:
Mechanical design of the beam line and the PETS tank (skills: Mechanical engineer, draftsman).
Design and fabrication of high power rf components (skills: rf engineer, mechanical engineer, draftsman).
Design and fabrication of PETS (skills: rf engineer, mechanical engineer, draftsman).
Control of the quadrupole movers (skills: PLC, controls).
Design and fabrication of rf electronics for data acquisition (skills: electronic engineer).

CONCLUSIONS

The design of the test beam line is mainly determined by the energy loss and the available geometrical aperture for the beam. Due to the lower energy in CTF3 compared to the CLIC drive beam a deceleration down to 10% of the initial energy is not possible. The maximum extractable energy for the nominal beam parameters is about 46% which corresponds to more than 2 GW of 30 GHz rf power. The experiment will be very relevant for CLIC because the beam to be transported without losses has a much lower energy and the wake field effects are more severe. TBL will allow simulation codes and criteria used for the design of the CLIC decelerator as well as alignment procedures to be benchmarked. Furthermore it will be an engineering test facility for CLIC PETS and their infrastructure giving valuable input for further optimization of the CLIC module design. The rf power produced, being in the GW range, can be used at a later stage for simultaneous testing of rf components and accelerating structure with high power.

It is envisaged to build a FODO lattice with 16 cells, filling up entirely the available space, but to equip only 8 cells in a first stage with PETS. After gaining some experience with the beam line additional cells will be installed. According to the simulations discussed above the nominal beam can not be transported without losses to the end of TBL in a 16 mm aperture. It would be possible if, the input energy is higher, the emittance is smaller or the beam current is lower than anticipated. Due to the fully loaded operation of the CTF3 linac it is possible to trade off beam energy and current. However a lower beam current means lower extractable energy which is not desirable. It is foreseen to upgrade CTF3 with a photo injector which promises a much better emittance. This would allow decelerating the beam through the entire length of the test beam line without losses. The photo injector in principle would be able to produce two bunches with the right distance to be combined later on in the combiner ring to probe the wake fields from the PETS directly.

Clearly more resources provided by CERN or collaborations are needed to construct TBL within the schedule presented. Some money will be needed this year to launch design and prototypes. The main discrepancy between the budget foreseen and the budget needed appears in 2009 where most of the PETS structures have to be purchased. Serious bottle necks are expected in the area of mechanical engineering and design. Currently very little is known on how to build the PETS and high power components.

It is recommended to launch the production of two prototype PETS at 30 GHz now to avoid further delays before the frequency question is solved. One could be build by CIEMAT and the other one by CERN. If successful, two PETS could be available when needed (see schedule). For the rest of the PETS the frequency decision has to be done as soon as possible but at latest at the end of this year.

The BPM foreseen in the modules is not yet well defined. The Spanish collaboration between Valencia and Barcelona committed to develop a prototype comprising the BPM and front end electronics to be tested in spring 2007. This development will need significant support from the CERN pick-up group. The collaboration envisages to ask for resources to build all 16 BPM’s needed.

A project has to be set up to design and build the high frequency signal acquisition system needed to monitor more than 30 rf signals in TBL. This effort has to start as soon as possible.

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